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Examining the structure of visual analogue scales to capture motivation to eat in fasting and post-meal conditions

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ABSTRACT

The visual analogue scale (VAS) methodology for tracking hunger, fullness, desire to eat and prospective consumption attempts to capture conceptually distinct but related dimensions of motivation to eat. It is the most commonly used methodology to measure subjective motivation to eat in human appetite and energy balance research.

The current paper examined the underlying factor structure of the 4 motivation to eat VAS: 1) in 552 participants from 13 studies at the Human Appetite Research Unit (HARU) at the University of Leeds through exploratory factor analysis (EFA) and confirmatory factor analyses (CFA) in fasting and post-meal conditions; 2) in 151 participants of the multi-center DiOGenes study through CFA in fasting and post-meal conditions before and after weight loss.

EFA results indicated that >60 % of the variance between the VAS variables was explained by one underlying factor. The CFAs confirmed that the one-dimensional structure presented an overall good model fit. The 4 VAS questions presented high factor loadings. The one-dimensional structure also revealed high construct reliability and convergent validity across the 13 studies. A second analysis further confirmed a one-factor structure in fasting and post-meal conditions before and after weight loss. Measurement invariance testing was conducted across sex and fasted vs non-fasted conditions. Results indicated model invariance across sex at the configural, metric, and scalar levels, and partial metric invariance across conditions.

This current analysis indicates that hunger, fullness, desire to eat and prospective consumption VAS questions contribute to a single latent factor that should be used as a composite measure of the underlying process of motivation to eat. Additionally, this work suggests new methods should be developed to identify and measure different dimensions of motivation to eat states.

1. Introduction

The field of human ingestive behaviour is still quite some way from developing an integrated theoretical framework to describe and measure traits and states related to motivation to eat-often called appetitive traits and states (Dakin et al., 2024c; Dakin, Stubbs, & Finlayson, 2023; Stubbs et al., 2023). There is still a need to articulate the key underlying constructs that describe and predict eating behaviour to enable development of consistent, standardised and psychometrically validated measurements of the most important eating-related traits and states that can be used and compared across a variety of laboratories, interventions and situations (Dakin et al., 2024a).

As regards motivational states to eat, over 100 years ago studies by Craig (1917) suggested that motivated behaviours appear to show

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anticipatory, consummatory and cessation or sated phases. It therefore seems both logical and informative to attempt to measure motivational states related to eating behaviour (Craig, 1917). In animal studies, motivations to eat are essentially latent constructs that can be inferred from the eating behaviour of the subject. An advantage of studying human behaviour is that humans can self-report subjective experiences of motivation, sensations and attitudes. Freyd (1923) originally noted that such ratings are the only practical equivalent of objective measurements for many types of psychological phenomena particularly introspective or verbally reported data (Freyd, 1923). It has been argued that subjective and psychometric data yield important information that enables researchers to better interpret eating behaviour in both real-life and experimental conditions (Stubbs et al., 2000).

The most commonly used methodology for the measurement of motivation to eat is the visual analogue scale (VAS) method of Blundell and Rogers, and Hill and Blundell (Blundell & Rogers, 1980; Hill & Blundell, 1982). This was an elaboration of the single question originally asked in the Hunger Scale initially used by Silverstone and Stunkard (Silverstone & Stunkard, 1968). Preoccupations with thoughts of food, desire to eat, gastric sensations of fullness and urge to eat, were all questions initially used by Monello and Mayer's assessment of hunger sensations in 603 men, women, boys and girls (Monello & Mayer, 1967) and subsequently included in the 4-item visual analogue scale method most commonly used. The VAS typically takes the form of a 100-mm horizontal line anchored at either end by extreme subjective states (Silverstone & Stunkard, 1968). The horizontal line reflects a continuum in which the participant marks a point that best represents a subjective feeling at a particular time (e.g., pre- and postprandial hunger). The most commonly used version of this questionnaire includes 4 measures specific to the questions of: hunger, "How hungry do you feel?" (Not at all hungry – As hungry as I've ever felt; Silverstone & Stunkard, 1968); desire to eat, "How strong is your desire to eat?" (Very weak – Very strong); fullness, "How full do you feel?" (Not at all full – As full as I have ever felt); prospective consumption, "How much do you think you could eat now?" (Nothing at all – A large amount). In Blundell's theoretical framework, the first two commonly used questions ("How hungry do you feel?", "How strong is your desire to eat?") are considered indices of the construct 'hunger'. The last two questions are considered indices of the construct 'satiety' ("How much do you think you could eat now?", "How full do you feel?"). Earlier versions of the scales also asked two additional questions "How strong is your urge to eat?" (Very weak – Very strong) and "Preoccupation with thoughts of food" (No thoughts of food – Very preoccupied/difficult to concentrate on other things).

Historically, the 4-item scale has become more widely used and the current analyses therefore focused on that version of the scale. These scales have been used extensively in numerous studies examining their relationship to, *inter alia,* food preloads or test meals (e.g., Blundell et al., 1993), pharmacological agents that affect motivation to eat (Blundell et al., 2017; Friedrichsen et al., 2021; Gibbons et al., 2021; Halford et al., 2010; Schmidt et al., 2014), systematic manipulations of the whole diet (Hall et al., 2019; Stubbs et al., 1994, 1996a, 1996b, 1997; Stubbs & Harbron, 1995), exercise interventions (Caudwell et al., 2008; Hughes et al., 2003; Stubbs, Sepp, Hughes, Johnstone, Horgan, et al., 2002; Stubbs, Sepp, Hughes, Johnstone, King, et al., 2002; Whybrow et al., 2008), subjects recording their free-living food intake (Whybrow et al., 2006, 2007) and weight loss interventions (Andriessen et al., 2018; Sumithran et al., 2011; Turicchi et al., 2020). The scales have been adapted for electronic devices (Gibbons et al., 2011; Stratton et al., 1998; Zhu et al., 2023).

Generally, adults appear to use terms such as hunger, appetite, satiation and satiety as aggregate descriptions of several sensations or motivations they recognise as predictors of their normal behaviour (Dakin et al., 2024b; Stubbs et al., 2000). Scientifically, there is a lack of consensus on the definition of these constructs (Stevenson et al., 2024). These VAS scales show considerable variability in how they are rated between individual participants. Visual analogue scales for motivation to eat exhibit a good degree of within-subject reliability and validity in that they broadly predict the behaviour they aim to measure the rating can be compared under conditions where it should change if sensitive (e.g. nutrient loads, anorectic drugs) and the ratings show test-retest reliability in a series of earlier studies when comparing the ratings on paper and pen to electronic devices (Stubbs et al., 2000). However, they cannot be used as a proxy for quantitative variables such as energy intake and they can be insensitive to small manipulations (Stubbs et al., 2000). The scales are often administered hourly and time of day often accounts for 20–30 % of the variance in subjective motivations to eat. Inter-subject variation in use of the scales themselves can account for >50 % of the variance in ratings (Stubbs et al., 2000). Analyses should take these sources of variability into account. There have been studies of the reliability and reproducibility of these scales across different delivery platforms as well as correlations with energy intake (Flint et al., 2000; Stratton et al., 1997; Zhu et al., 2023).

Despite their historical widespread use (e.g., Blundell et al., 2010), few studies have assessed the psychometric construct-validity and reliability of this methodology. Specifically, there has been a lack of work examining the factorial validity of the scales.

It remains a matter of debate as to whether the scales are measuring qualitative sensations, symptoms, simple perceptions or whether they related to some underlying construct. If they are simple sensations, symptoms, or perceptions it is unclear whether the measurements distinguish different processes or simply overlap. Historically it has appeared difficult to identify a consistent constellation of sensations or symptoms that characterise motivation to eat (Monello & Mayer, 1967; Stevenson et al., 2023). Even if they are simple sensations, it is useful to enquire whether these are components of a construct (see Stevenson et al., 2024) and below). As noted by Blundell et al., the primary motivation for the four basic scales used appears to be 'pragmatic' and to ensure uniformity in the field, combined with the observation that these scales "enjoy a history of widespread and consistent use and acceptance over several decades in many different countries and laboratories, with different test stimuli and subject groups" (Blundell et al., 2010). Blundell et al. note that while studies find very high and sometimes near perfect correlations amongst these different measures of motivation to eat, it has become common practice to use the multiple scales. "Whilst it might be acceptable to use a mean score of several of these scales, there has been little systematic study of these points" (Blundell et al., 2010). There is no universally accepted definition of the constructs involved (hunger and satiety; Stevenson et al., 2024) and their overlap with vernacular usage is both a potential strength and contaminant of any constructs and their measures.

It is useful within the constraints of this discussion to define what we mean by a construct. Generally speaking, constructs are abstractions that have integrative and explanatory roles in theory and practice (De Boeck et al., 2023). In other words, they help develop theories to explain mechanisms underlying observed patterns of human behaviour. In this case, motivational mechanisms related to eating behaviour. Constructs are generated (by psychologists) in the hypothetical domain and operationalised in the measurement domain often in the form of self-report, question-based items that cluster together to explain a psychological phenomenon such as motivation to eat or not to eat. It is important to note that definitions are not always agreed and consensus not always achieved in relation to these constructs. See (De Boeck et al., 2023) for a recent discussion. For the purposes of this paper, we consider a construct to be a theoretically informed, conceptual abstraction that can be translated operationally into a measurement or series of measurements, which have potential to explain a commonly agreed psychological process or behaviour. In this context, the construct is motivation to eat or not eat; the behaviour is eating. It is also important to note that because definitions are, and agreement of definitions is often not universal, it is necessary for the measurement items related to a construct to be empirically validated in some way. Those validations are usually psychometric in nature (Boateng et al., 2018; DeVellis, 2003, pp.

1–216). Constructs should also be validated or verified by evaluation of their relationship to the behaviours or phenomena with which they are, hypothetically at least, supposed to be linked, through mechanisms of action. Once defined, constructs often become and should be debated, and if necessary refined, as the subject of conceptual scrutiny in their own right, which is part of the purpose of this paper.

In translating the above background into psychometric measurements of eating motivation, it is important to ask what exactly are we measuring? Are the items on the scale measuring conceptually or theoretically distinct constructs? These ratings co-vary to a great extent and it is therefore reasonable to ask whether the questions used relate to a single phenomenon of 'motivation to eat', or to more than one underlying motivation or process (Stubbs et al., 2000). In previous work in two experiments collectively involving 32 subjects, using a 6-item version of the scale we have applied principal components analysis to the six original100-mm visual analogue scales to identify distinct dimensions in the responses to the questions (Reid et al., 1998). In almost every case the first principal component was essentially an average of the six visual analogue ratings. This component explained at least 85 % of the variation observed across the six VASs and can be thought of as a general measure of the latent construct of 'motivation to eat'. For the majority of subjects, a small second principal component was a contrast between unfullness (100-fullness) and some or all of the four ratings desire to eat, prospective consumption, urge to eat and thoughts of food. This suggested a compound rating 'motivation-fullness', contrasting a fullness-based sensation, as measured by unfullness, with motivation to eat, as measured by desire, urge, prospective consumption and thoughts of food. In each study, the first two principal components explained over 90 % of the variation. However, a key limitation of this study was the small sample size (Reid et al., 1998).

The present work, involving two studies, aimed to examine the factorial structure of the 4 item motivation to eat VAS questions that have been widely used across multiple countries over several decades – hunger, fullness, desire to eat, prospective consumption – across a large number of participants of different studies of appetite and energy balance with different experimental conditions (Blundell et al., 2010). Adopting a data-driven, reflective measurement approach (e.g., Borsboom, 2006), we examined the plausibility that these items reflect a common latent construct through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA).

1.1. Study I. Factorial structure of the VAS – exploratory factor analysis and confirmatory factor analysis

1.1.1. Method

1.1.1.1. Subjects. Data from 13 studies (three unpublished and 10 published (Beaulieu, Casanova, et al., 2020; Beaulieu, Hopkins, Blundell, & Finlayson, 2017; Beaulieu, Hopkins, Long, et al., 2017; Beaulieu, Oustric, et al., 2020; Buckland et al., 2018; Casanova et al., 2021; Dalton et al., 2013; Dalton et al., 2015; Hollingworth et al., 2019; Myers et al., 2019) conducted at the Human Appetite Research Unit (HARU) at the University of Leeds between 2014 and 2020 were aggregated for Study 1 (Sample 1). Individual study sample size ranged from 30 to 89 (total n = 552; 82 % female; age = 31 ± 12 y [individual (participant-level) range 18–65; study-level mean range 21–41]). Five studies included participants from a range of BMI categories, one was in participants with healthy weight only, four in participants with healthy weight and overweight, and three in participants with overweight/obesity (overall BMI = 25.8 ± 5.0 kg/m^2 [individual range 17.0–42.5; study mean range 21.8–33.3]; Table 1).

1.1.1.2. Procedure and materials. The factor structure of the 4 items (hunger, fullness, desire to eat and prospective consumption) was initially examined using aggregated data from the 13 studies conducted at the University of Leeds. Ten studies were cross-sectional and three were intervention studies. When studies included several conditions (nutritional manipulations), the control condition was used for the current analysis. The baseline measurements were used in the intervention studies. Ten studies used an electronic appetite rating system for VAS (Gibbons et al., 2011), three studies used pen and paper. The studies using the electronic appetite rating system presented the VAS items in the same order and had the same anchors; the three pen and paper studies differed in order of presentation of the items and differed slightly in the wording of the anchors (e.g., "How hungry do you feel now?" and "How hungry do you feel"). All VAS were recorded on a 100-point scale. In all studies, measurement days were conducted after an overnight fast, and after refraining from consuming alcohol and caffeine for at least 12h and exercising for at least 24h. VAS ratings for hunger, fullness, desire to eat and prospective food consumption were assessed immediately before (fasting condition) and immediately after breakfast consumption (post-breakfast condition). In eight studies breakfast was equivalent to 25 % of resting metabolic rate (as measured using indirect calorimetry; GEM, Nutren Technology Ltd.), one study used fixed energy according to three energy requirements bands, two used fixed energy (240 kcal and 300 kcal) and two involved ad libitum breakfasts. Mean breakfast energy intake was 367 ± 96 kcal [individual range 113–852 kcal; study mean range 236–478 kcal]).

1.1.1.3. Data analysis. The factor structure of the VAS was examined in the fasting condition through an exploratory factor analysis (EFA). The number of participants surpassed the recommended 10:1 cases-to parameter ratio required to confidently assess a model (Bentler, 1990) Correlations between VAS items were initially examined to ensure they

Table 1
Individual studies included and participants characteristics in Study 1.

Study	N (M/F)	Age (years)	BMI (kg/m^2)	FM (kg)	FFM (kg)	Mean VAS
Study 1 (Dalton et al., 2013)	34 (0/34)	25.24 ± 5.69	27.45 ± 5.46	26.61 ± 12.22	49.22 ± 6.33	43.52 ± 5.77
Study 2 (Dalton et al., 2015)	30 (0/30)	28.00 ± 10.56	23.13 ± 2.96	19.60 ± 5.49	43.11 ± 5.18	39.19 ± 7.96
Study 3 (Beaulieu, Hopkins, Blundell, & Finlayson, 2017)	39 (18/21)	30.13 ± 9.33	22.82 ± 2.30	14.90 ± 5.92	51.25 ± 11.02	43.24 ± 7.67
Study 4 (Beaulieu, Hopkins, Long, et al., 2017)	36 (11/25)	28.42 ± 9.02	23.07 ± 2.84	16.16 ± 5.31	49.31 ± 10.82	41.75 ± 8.27
Study 5 (Buckland et al., 2018)	89 (0/89)	41.33 ± 12.59	33.30 ± 3.54[a]	41.57 ± 9.37 [a]	47.52 ± 5.42[a]	42.17 ± 7.65
Study 6 (Hollingworth et al., 2019)	42 (0/42)	25.64 ± 7.94	21.97 ± 2.02	15.45 ± 5.02	43.04 ± 4.07	43.15 ± 7.27
Study 7 (Myers et al., 2019)	32 (0/32)	32.00 ± 11.36	28.20 ± 2.80	30.79 ± 7.49	46.24 ± 3.96	44.30 ± 6.42
Study 8 (Beaulieu, Casanova, et al., 2020)	46 (0/46)	34.93 ± 10.27	29.17 ± 2.40	33.44 ± 8.16	46.53 ± 5.64	51.12 ± 11.31
Study 9 (Beaulieu, Oustric, et al., 2020)	42 (17/25)	–	24.47 ± 3.25	–	–	38.19 ± 8.08
Study 10 (Casanova et al., 2021)	48 (0/48)	35.17 ± 10.25	21.83 ± 1.74	16.22 ± 4.05	42.87 ± 4.43	41.26 ± 5.69
Study 11 (unpublished)	30 (15/15)	28.23 ± 11.65	24.82 ± 3.33	18.18 ± 8.45	53.82 ± 11.86	40.42 ± 6.48
Study 12 (unpublished)	31 (19/12)	27.10 ± 10.62	25.06 ± 2.92	17.65 ± 9.43	56.67 ± 12.26	41.72 ± 10.11
Study 13 (unpublished)	53 (17/36)	20.74 ± 0.90	22.54 ± 3.00	–	–	47.01 ± 8.65
Total	552 (97/455)	30.89 ± 11.58[b]	25.78 ± 4.97[c]	24.76 ± 12.67[d]	47.76 ± 8.48[d]	40.04 ± 9.46

Note. Values are Mean ± SD. [a]n = 84, [b]n = 510, [c]n = 547, [d]n = 452. Superscripts indicate the number of participants (n) contributing to each variable. BMI – body mass index, FM – Fat Mass, FFM – Fat Free Mass, VAS – Visual Analogue Scale.

were significant, to continue with EFA (Field, 2013). Preliminary analyses of Skewness (SK) and Kurtosis (Ku) values confirmed the data were normally distributed with values of SK ranging from −0.35 (hunger) to −1.19 (fullness), and Ku values ranging from −0.25 (fasting) to 1.07 (fullness). Components were extracted using the criteria for Eigenvalues ≥1, the scree plot was examined and a Parallel Analysis was run. Parallel analysis was used because it more accurately estimates the number of factors in a data set than examining scree plots and using the Eigenvalue ≥1 criterion (Kaiser criterion). Global diagnostic indicators showed strong factorability of the correlation matrix for all variables in the fasting condition (Kaiser–Meyer Olkin = 0.78, Bartlett's test of sphericity $x^2 = 1064.76$, $p < .001$). The factoring method used was maximum likelihood analysis (ML) because ML enables the computation of a wide range of indices of goodness of fit and allowed statistical significance testing of factor loadings (Fabrigar et al., 1999). An oblique rotation method was used because factors were expected to correlate and this type of rotation theoretically creates a more accurate and reproducible solution (Costello & Osborne, 2005). Since there is no widely preferred method of oblique rotation with all tending to produce the same results, direct oblimin was used (Fabrigar et al., 1999). Finally, items attaining a loading of 0.32 or higher on any factor were retained (Tabachnick et al., 2007).

The identified structure was then confirmed through a Confirmatory Factor Analysis (CFA) in the immediate post-breakfast condition. Global diagnostic indicators revealed strong factorability of the correlation matrix for all variables in the post breakfast condition (Kaiser–Meyer Olkin = 0.82, Bartlett's test of sphericity $x^2 = 1261.70$, $p < .001$). Variables were entered into the CFA based on the rotation matrix suggested by the EFA. The ML estimation method was used. The CFA was analysed from the covariance matrix and the latent variables were allowed to correlate. The following indices were used to examine model fit; Chi-square (χ^2); Normed Chi-Square (χ^2/df), with 2–5 indicating good fit; Comparative Fit Index (CFI), with 0.90 suggesting good fit; Root Mean Square Error of Approximation (RMSEA), with 0.05–0.08 indicating reasonable error and acceptable fit; and the Standardized Root-Mean-Square Residual (SRMR), with a value below 0.08 indicating good fit (Kline, 2015; Tabachnick et al., 2013). Construct validity was further established through the calculation of the Composite Reliability (omega) indicator and the Average Variance Extracted (AVE; indicator of convergent validity) (Hair et al., 2010). The CFA was conducted using the R package 'lavaan' version 0.6–18 (Rosseel, 2012). Figures were plotted using the 'semPlot' package (Epskamp et al., 2019).

1.1.2. Results

1.1.2.1. Exploratory factor analysis. The VAS items correlation matrix (Table 2) revealed moderate to strong correlations between the variables. The four items revealed high communalities (>0.54). The visual inspection of the scree plot and parallel analysis suggested a one-dimensional structure, and a borderline second factor (Fig. 1). The latent root criterion indicated the extraction of one factor (with an eigenvalue of 2.78). The four items showed high composite reliability with an omega coefficient of 0.86, and high convergent validity with an average variance extracted (AVE) of 0.61.

Following these preliminary analyses, an EFA was performed setting the variables to load on one factor. Table 3 shows the factor loadings for the one factor EFA. The one-factor EFA goodness of fit indices were: RMSR = 0.03, TLI = 0.944. Total variance explained was 61 %. Given that items of the VAS have traditionally been used as separate scores, and that the parallel analysis suggested marginal support for retaining up to two factors, an additional EFA specifying a two-factor solution was conducted. Items were considered to load on a factor if the loading was ≥0.32 and < 0.32 on any other factor. Results of the two-factor EFA are reported in the Supplementary Materials. However, this solution was not interpretable due to model identification constraints (i.e., a two-factor model cannot be identified with only four items). Furthermore, the items in each of the two factors are hard to interpret from a theoretical or conceptual perspective. Accordingly, only the one-factor solution was considered testable and is reported here.

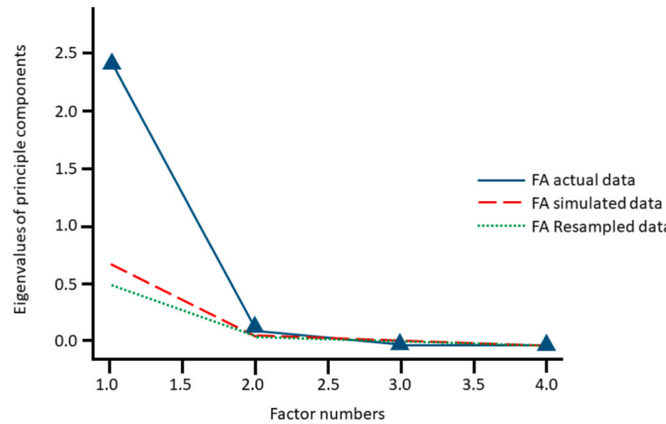

Fig. 1. Parallel analysis scree plot showing observed eigenvalues (blue) and eigenvalues from resampled data (red) for the exploratory factor analysis. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
VAS items correlation matrix ($n = 552$).

	Hunger	DTE	PFC
Hunger	1		
DTE	0.76***	1	
PFC	0.63***	0.63***	1
Fullness	−0.61***	−0.48***	−0.41***

Note. ***$p < .001$; DTE = desire to eat, PFC = prospective food consumption. Total sample (n = 552). Not all participants contributed to every variable.

1.1.2.2. Confirmatory Factor Analysis. Based on the EFA results, the one-factor model was tested with CFA. The one-factor model included all variables under one factor. The one-factor model demonstrated acceptable fit to the data, with ($\chi^2 = 12.165$, df = 2, p = .002, CFI = 0.991, TLI = 0.974, RMSEA = 0.099, SRMR = 0.016, see Fig. 2). Although the RMSEA slightly exceeded the conventional cutoff of 0.08 (Hu & Bentler, 1999), other indices indicated good fit. The four items showed high composite reliability with an omega coefficient of 0.89, and high convergent validity with an AVE of 0.67.

Due to the slightly elevated RMSEA value, we explored modification indices, which suggested the residual between fullness and desire to eat was relatively high (MI = 11.160). We therefore allowed these residuals to correlate, which improved the model fit, ($\chi^2 = 0.266$, df = 1, p = .606, CFI = 1.000, TLI = 1.004, RMSEA = 0.000, SRMR = 0.003). However, this revised model had only 1 degree of freedom, a condition under which RMSEA is known to be unreliable and potentially misleading

Table 3
Factor loadings for the one-factor EFA in Study 1 ($n = 552$).

EFA 1 Item	ML1	Commonality	Uniqueness	Complexity
Hunger	0.92	0.84	0.16	1.00
DTE	0.83	0.69	0.31	1.00
PFC	0.70	0.50	0.50	1.00
Fullness	−0.63	0.40	0.60	1.00

Note. DTE = desire to eat, PFC = prospective food consumption, commonality = the proportion of variance in the item that is explained by the common factor, uniqueness = the proportion of variance in the item that is not explained by the common factor, complexity = the number of factors that explain the variance of the item.

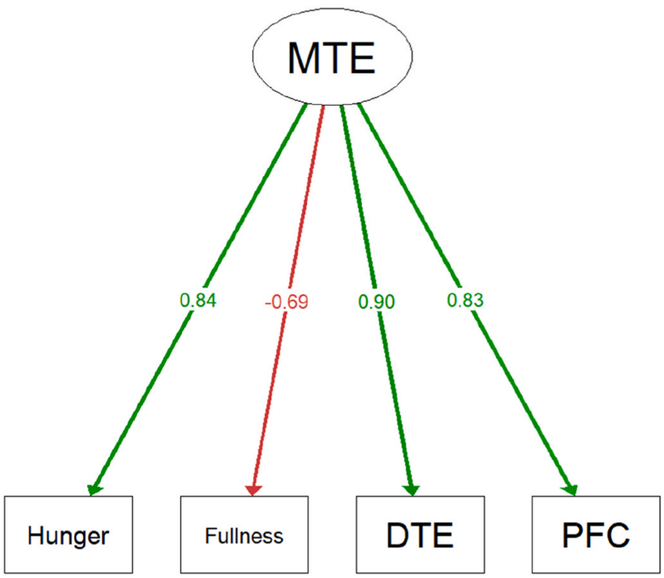

Fig. 2. One-factor CFA in Study 1. Note. MTE = motivation to eat, DTE = desire to eat, PFC = prospective food consumption. Numbers represent standardised loadings. Green lines indicate a positive relationship with the latent construct and red an inverse relationship. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(Kenny et al., 2015). Given the theoretical coherence of the one-factor solution and the limitations of interpreting RMSEA with low degrees of freedom, we retained the original one-factor model for subsequent analyses.

1.1.2.3. Measurement invariance testing. Based on the model fit of the one-factor model, we deemed that there is evidence of a one factor structure of the 4-item VAS motivation to eat scale to consider conducting measurement invariance tests. Measurement invariance testing was conducted to compare invariance across sex (male vs female) and condition (fasting vs post-breakfast). For the comparison of sex, the post-breakfast sample was used. For the comparison of condition, the full sample was combined. For both analyses, two groups were compared, which aligns with the practical suggestion of Putnick and Bornstein (2016) to compare two or three groups. The full sample (n = 552) exceeds the minimum recommendation of 200 participants per group (Meade & Bauer, 2007). As only two groups with a single 4-tem subscale were being investigated, adequacy of sample size to conduct measurement invariance tests was justified.

For all models, the chi-square model fit test and multiple additional fit indices were reported. To evaluate the overall factor model across condition groups (fasting and post-breakfast) as well as the configural, metric, and scalar models, the total model chi-square and the CFI, RMSEA and SRMR were reported. The next level of invariance was not supported if the higher-level model increased RMSEA by more than 0.015 or decreased CFI by more than 0.01 (Chen, 2007).

1.1.2.4. Measurement invariance (sex). The configural model demonstrated good fit, χ^2 (4) = 11.798, p < .001, CFI = 0.993, RMSEA = 0.087, SRMR = 0.014, indicating that the factor structure was consistent across sex. The metric invariance model, which constrained factor loadings to be equal across sexes, also showed acceptable fit, χ^2 (7) = 19.501, p < .001, CFI = 0.989, RMSEA = 0.083, SRMR = 0.033. The change in fit indices from the configural model (ΔCFI = −0.004, ΔRMSEA = −0.004, ΔSRMR = 0.019) were within recommended thresholds, supporting metric invariance. The scalar invariance model, which additionally constrained item intercepts, yielded χ^2 (10) = 30.796, p < .001, CFI = 0.981, RMSEA = 0.089, SRMR = 0.039. The changes in fit from the metric model (ΔCFI = −0.007, ΔRMSEA = 0.007, ΔSRMR = 0.006) also met the criteria for scalar invariance. These results support the conclusion that the measurement model is invariant across sex at the configural, metric, and scalar levels, allowing for valid comparisons of latent means between male and female participants (see Table 4).

1.1.2.5. Measurement invariance (condition: fasting vs post-breakfast). The configural model demonstrated acceptable fit, χ^2 (4) = 34.142 p < .001, CFI = 0.987, RMSEA = 0.119, SRMR = 0.018, indicating that the factor structure was similar across conditions. The metric invariance model, which constrained factor loadings to be equal across conditions, showed a substantial decrease in model fit, χ^2 (7) = 96.236, p < .001, CFI = 0.960, RMSEA = 0.154, SRMR = 0.082. The changes in fit indices from the configural model (ΔCFI = −0.026, ΔRMSEA = 0.036, ΔSRMR = 0.064) exceeded those commonly accepted, indicating a lack of metric invariance (see Table 5).

To identify which loadings contributed most to the lack of metric invariance, the standardised loadings and modification indices were examined. This indicated that the loading for fullness was different between the conditions (β = −0.683 fasted vs β = −0.595 post-breakfast), whilst the loadings for hunger were similar (β = 0.866 fasted vs β = 0.869 post-breakfast), and there were small differences between DTE (β = 0.849 fasted vs β = 0.897 post-breakfast) and PFC (β = 0.756 vs β = 0.790 post-breakfast). A partial metric invariance model was therefore tested in which the loading for fullness was freely estimated across groups, while the other loadings were constrained.

This model demonstrated acceptable overall fit, with χ^2 (6) = 70.431, p < .001; CFI = 0.971; TLI = 0.943; SRMR = 0.056; RMSEA = 0.142 and improved fit indices over the metric model (ΔCFI = 0.011, ΔRMSEA = −0.026, ΔSRMR = −0.013). These results support partial metric invariance of the MTE factor, with evidence that the relationship between fullness and the latent factor differs by condition (fasted vs fed).

1.2. Study 2 – confirmatory factor analyses in an independent sample under different conditions

1.2.1. Method

1.2.1.1. Subjects. Data from an independent data set (following scholars' recommendations for CFA analyses; e.g., Brown, 2015; Kline, 2015) using the test meal study of the multi-center DiOGenes trial (for details please see (Andriessen et al., 2018)) at baseline (visit 1) and after an 8-week weight loss intervention leading to ≥8 % body weight loss (post-WL; visit 2) were used for this study (Sample 2; n = 151; 63 % female; age = 41 ± 5 y [range 26–54]; baseline BMI = 34.4 ± 4.3 kg/m^2 [range 26.9–45.9]).

1.2.1.2. Procedure and measures. The 4-item VAS were recorded on a 100-point scale on a web-based questionnaire delivery platform. Participants attended the lab overnight fasted and consumed a fixed test meal at lunchtime providing 1.6 MJ (382 kcal). Appetite ratings for hunger, fullness, desire to eat and prospective food consumption were obtained 15 min before and 15 min after the start of the test meal

Table 4
Fit indices for Configural, Metric, and Scale Invariance Models and differences in fit indices (sex).

Model	$\chi2_{Y-B}$	df	p	CFI	RMSEA	SRMR
1. Configural	11.798	4	<0.001	0.993	0.087	0.014
2. Metric	19.501	7	<0.001	0.989	0.083	0.033
1 vs 2	7.723	3	0.053	−0.004	−0.004	0.019
3. Scalar	30.796	10	<0.001	0.981	0.089	0.039
2 vs 3	11.295	3	0.010	−0.007	0.007	0.006

Note. Fit indices are robust forms.

Table 5
Fit indices for Configural, Metric, and Scale Invariance Models and differences in fit indices (condition).

Model	$\chi 2_{\text{Y-B}}$	df	p	CFI	RMSEA	SRMR
1. Configural	34.142	4	<0.001	0.987	0.119	0.018
2. Metric	96.236	7	<0.001	0.960	0.154	0.082
1 vs 2	62.095	3	<0.001	−0.026	0.036	0.064
3. Partial Metric	70.431	6	<0.001	0.971	0.142	0.056
3 vs 2	25.806	1	<0.001	0.011	−0.013	−0.026

Note. Fit indices are robust forms.

(Andriessen et al., 2018).

1.2.1.3. Data analysis. The factor structure of the VAS in Study 2 was examined using CFA. The same model fit criteria and factor loading thresholds used in Study 1 were applied. Each of the VAS items were measured under 4 conditions (baseline: fasting pre-lunch, post-lunch; and post-WL: fasting pre-lunch, post-lunch). The number of participants surpassed the recommended 10:1 cases-to parameter ratio required to confidently assess a model (Bentler, 1990). Correlations between VAS items were initially examined to ensure they were significant (Field, 2013). Preliminary analyses of Skewness (SK) and Kurtosis (Ku) values confirmed the data were normally distributed with values of SK ranging from −0.06 (Fullness) to 0.33 (PFC), and Ku values ranging from 2.52 (DTE) to 3.01 (Fullness). Global diagnostic indicators indicated strong factorability of the correlation matrix for all variables in the post breakfast condition (Kaiser–Meyer Olkin = 0.83, Bartlett's test of sphericity $x^2 = 486.13$, $p < .001$). A series of CFA's were conducted in the Diogenes sample, with all CFA's using a one-factor model. CFA1 combined the 4 conditions, CFA2 included only the baseline pre-lunch data, CFA3 included only the baseline post-lunch data, CFA4 included only the post-WL pre-lunch data and CFA5 included only the post-WL post--lunch data. The ML estimation method was used. The CFA was analysed from the covariance matrix and the latent variables were allowed to correlate. Measurement invariance testing was not conducted in this study due to the small sample size (n = 151).

2. Results

2.1. Confirmatory factor analyses

The items correlation matrix for CFA1 (all 4 conditions combined, Table 6) revealed strong correlations between the variables. Results showed that the one factor model (CFA1) met the criteria for goodness of fit ($\chi^2 = 7.032$, df = 6, p = .030, CFI = 0.990, TLI = 0.969, RMSEA = 0.129, SRMR = 0.017, see Fig. 3). The four items showed high composite reliability with an omega coefficient of 0.93, and high convergent validity with an AVE of 0.76.

Results showed that a one-dimensional solution presented a very good model fit for all separate conditions (Table 7). The one factor model in the fasted pre-weight loss condition (CFA2) met the criteria for goodness of fit ($\chi^2 = 2.376$, df = 2, p = .305., CFI = 0.999, TLI = 0.997, RMSEA = 0.035, SRMR = 0.011). The one factor model in the fed pre-weight loss condition (CFA3) met the criteria for goodness of fit (χ^2 = 6,648, df = 2, p = .036, CFI = 0.988, TLI = 0.965, RMSEA = 0.125, SRMR = 0.019). The one factor model in the fasted post-weight loss condition (CFA4) met the criteria for goodness of fit ($\chi^2 = 3.303$, df = 2, p = .192, CFI = 0.996, TLI = 0.987, RMSEA = 0.073, SRMR = 0.018). Lastly, the one factor model in the fed post-weight loss condition (CFA5) met the criteria for goodness of fit ($\chi^2 = 1.919$, df = 2, p = .383, CFI = 1.000, TLI = 1.001, RMSEA = 0.000, SRMR = 0.012). RMSEA values were interpreted with caution given evidence that RMSEA can be inflated in models with very small degrees of freedom. The items in CFA's 2–5 showed high composite reliability and high convergent validity (see Table 7).

Table 6
Item correlations matrix (n = 151).

	Hunger	DTE	PFC
Hunger	1		
DTE	0.86***	1	
PFC	0.76***	0.79***	1
Fullness	−0.74***	−0.70***	−0.71***

Note. DTE = desire to eat, PFC = prospective food consumption.

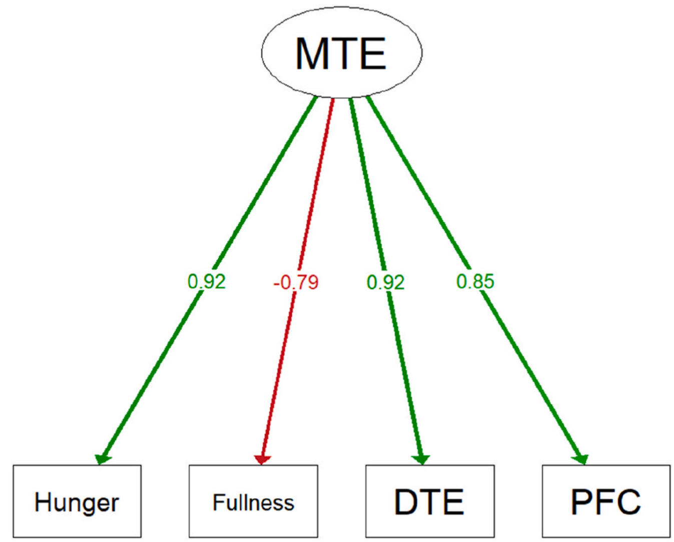

Fig. 3. One-factor CFA1 in Study 2 (all 4 conditions combined). Note. MTE = motivation to eat, DTE = desire to eat, PFC = prospective food consumption.

Table 7
CFA standardised loadings, omega coefficient and AVE for the different conditions in the Diogenes sample (n = 151).

Item	Fasted Pre-WL	Fed Pre-WL	Fasted Post-WL	Fed Post-WL
Hunger	0.94	0.90	0.91	0.83
DTE	0.89	0.87	0.89	0.94
PFC	0.78	0.85	0.72	0.89
Fullness	−0.72	−0.77	−0.77	−0.82
Omega	0.90	0.91	0.89	0.93
AVE	0.70	0.72	0.68	0.76

Note. Pre-WL: pre weight loss, Post-WL: post weight loss, DTE: desire to eat, PFC: prospective food consumption; AVE: Average Variance Extracted.

3. Discussion

The current analyses were motivated by a preliminary study we conducted 27 years ago (Reid et al., 1998) which identified two potentially useful independent factors - a major and a minor one) that can be derived from the 6-item version of the VASs initially described by Hill and Blundell (1982). Following a data-driven approach and in line with a reflective measurement model (e.g., Borsboom, 2006), the present study examined the factorial structure of the VAS motivation to eat state methodology in a much larger sample in the more frequently used 4-item scale across a number of studies, under distinct conditions and rating methods (pen vs. paper).

In Study 1, the analysis of the VAS structure was conducted on aggregated data from 13 studies where VAS scores were recorded after an overnight fast, before and after breakfast consumption. An EFA indicated the plausibility of one factor, which was confirmed in the subsequent CFA analyses. A limitation of sex in the invariance testing was that there were more women than men in the sample. This implies that findings may be more strongly influenced by the larger group (80 %

Women) and so invariance may be more reflective of their response. Future studies should include larger sample sizes with more equal representation of population subgroups such as men and women. The loading for fullness and prospective food consumption differed slightly between the fasted and fed conditions.

The current analysis indicate that the four items can be adequately modelled as a single factor. In Study 1, the EFA and the CFA found that same unidimensional factor structure, suggesting that in the fasted and fed state, the underlying structure of the VAS is the same. Study 2 confirmed this one-dimensional structure, with the results supporting the one-factor model in all 4 conditions and when combined. Due to the small sample size in Study 2, it was not possible to test measurement invariance. Future research should examine the measurement invariance of the VAS items and whether a unidimensional structure holds across fasted and non-fasted states in larger and more diverse samples. We do expect this to be the case given this is only a 4-item scale (due to model identification issues: Costello & Osborne, 2005; Kline, 2015). In this sense, the results of study 2 are preliminary, and though the fit and loadings were strong for a 1 factor solution, this is a limitation of the current study. Future work, which is underway, should include a larger item pool capturing different dimensions of motivation to eat states, as potential multidimensionality cannot be effectively tested with only four items. In addition, future work should include larger and more diverse samples.

Measurement invariance analysis also implies that there are different dimensions to the motivation to eat that may change based on situations such as fasted and fed states. However, the current analyses also strongly suggest that this 4-item motivation to eat VAS does not capture those dimensions and should be treated as a single latent construct. In other words, if other factors (or dimensions) relating to motivation to eat exist, they cannot be clearly obtained by using these specific measures, either in the 4-item VAS examined here or the 6-item version we examined 27 years ago. These findings may be evidence that alternative methods or new measurement tools are needed to tap into distinct components of motivation to eat, as such constructs cannot be meaningfully extracted from the current 4-item VAS measurements. Future development of state measures to assess motivation to eat, currently in progress, should include a broader item pool capturing different dimensions of motivation to eat states, in addition to larger and more diverse samples. Blundell (1979) initially discussed the differences between hunger, appetite, satiation and satiety and their respective influences on eating behaviour, concluding that they are closely linked processes, but which can operate independently of each other. As far as the 4-item VAS scale is concerned, the four questions appear to be better described by a single underlying factor, namely 'motivation to eat,' compared to treating each (e.g., hunger, fullness, desire to eat, prospective food consumption) as separate/unique scale scores, as has been done in prior work (e.g., Andriessen et al., 2018; Friedrichsen et al., 2021; Hall et al., 2019; Stribiţcaia et al., 2020; Turicchi et al., 2020). Psychometrically speaking, hunger is one of several items loading positively onto the motivation to eat factor, whereas Fullness showed a moderate inverse loading consistent with motivation not to eat. A common latent factor does not mean the individual items in the scale are identical, otherwise they would be completely redundant. However, it means that they share sufficient variance that they are measuring a single factor. Each of the 4 items has a uniqueness of <50 %, except fullness which is 40 %. However, it is reverse scored and participants treat reverse scored items differently, which could artificially inflate its apparent uniqueness (Weijters & Baumgartner, 2012). Thus, if these data are generally applicable to larger numbers of subjects, it would appear that questionnaires used to monitor motivation to eat could be redesigned to account for any different dimensions of that motivation. It is likely that other dimensions of motivation to eat states exist that are not captured by this scale. It also may be useful to design and validate scales with the specific purpose of contrasting ratings with each other to measure different dimensions of motivation to eat. Given this analysis suggests that the main framework for psychometric tracking of appetitive sensations can primarily be described by one underlying construct, the analyses raise the question of where do we go from here?

3.1. Implications

The current analyses in the present paper suggest that large samples of adult humans *rate* these scales as general motivation to eat or not eat, rather than distinct measurable biological or motivations processes (Blundell et al., 2009; Stubbs et al., 1998, 2000, pp. 283–325). Numerous studies have reported results for hunger, fullness, desire to eat and prospective food consumption sometimes finding significant responses for interventions for some items but not others (e.g., Stribiţcaia et al., 2020). It is not always clear what such differences, often on the border of power and significance mean in studies that report them (e.g., Turicchi et al., 2020). The most likely explanation is one of marginal, rather than different, item-specific effects. Given that this data-driven analysis supports a unidimensional interpretation of the current scale, we caution against interpreting intervention effects based on purported subscales within this VAS, as there is no psychometric justification for treating these items as separate factors. Furthermore, there is, as yet, no overarching theoretical or mechanistic rationale to explain such marginal differences between item-specific scores i.e. we do not have a clear or consistent explanation of what such small differences mean. The studies concerned often use limited sample sizes and effect sizes that appear significant but modest, further warranting caution in trying to interpret similar items as separate constructs related to different processes involved in motivation to eat. We therefore recommend treating these scales as items that measure the one underlying construct 'motivation to eat'. Indeed, it has become fairly common to develop aggregate scores of motivation to eat (appetitive) items (Mattes et al., 2005; Sadoul et al., 2014) which would appear to be a reasonable interpretation of the EFA and CFA and prudent use of this scale. It should be noted that, from a psychometric standpoint, in its current presentation, the 4-item VAS precludes the proper psychometric evaluation of a multi-factor solution (due to model identification issues: Costello & Osborne, 2005; Kline, 2015). Even though this simplest identifiable one-dimensional model demonstrated good fit and invariance, we cannot rule out the existence of underlying multi-dimensionality. Additionally, we suspect that there are other dimensions of motivation to eat states which are not captured by this current VAS scale but could be identified with new methodological developments that expand the item pool.

Current measurements do not articulate well the different dimensions of motivations (the reasons why adults eat what they eat). Importantly, participants are motivated to eat or not in different ways. This idea has been touched on previously (French et al., 2012; Sproesser et al., 2018) or using models related to motivations to drink alcohol (Jackson et al., 2003). An interesting approach has recently been provided by Stevenson et al. in their revisitation (Stevenson et al., 2023) of the work by Monello and Mayer 58 years ago (Monello & Mayer, 1967). Briefly, in considering one aspect of motivation to eat (interoceptive hunger), they collected new data in ~200 university students using the same 48 item hunger questions as used in 1967 (Monello & Mayer, 1967). They found that interoceptive hunger has 11 dimensions in this sample. While participants differed considerably in their combinations of items (interceptive hungers) these only represented 4 % of all possible permutations. Generally, each tended to include a focal, a diffuse and a negative effect-related dimension to interceptive hunger (Stevenson et al., 2023). We recommend similar systematic psychometric developments in the development of motivation to eat trait and state measurements.

In this context we have recently developed a psychometrically validated approach that is both theoretically informed (Berridge & Kringelbach, 2008; Berthoud, 2011; Kringelbach, 2004; Kringelbach et al., 2012; Stubbs et al., 2023) and evidence based (Dakin, Beaulieu, et al., 2023; Dakin, Finlayson, et al., 2023; Dakin, Stubbs, & Finlayson, 2023), to better understand and measure the different motivations for eating (Dakin, Beaulieu, et al., 2023; Dakin et al., 2023, 2024c; Dakin, Stubbs, & Finlayson, 2023). Our initial data dissecting eating motivation **traits** accords with dual process models and the neurobiology of eating behaviour, suggests that there are at least seven motivational dimensions to the construct of 'motivation to eat,' which are 1) reactive eating, 2) negative emotional overeating, 3) positive emotional eating, 4) restricted eating, 5) homeostatic eating, 6) eating for pleasure and 7) eating for health (Dakin, Stubbs, & Finlayson, 2023). The underlying structure of this model is stable across two very different populations (UK representative sample and participants of a multicomponent weight management programme), indicating the framework's generalisability across different contexts. Importantly, this model is predictive of body weight and body weight change (Dakin, Beaulieu, et al., 2023; Dakin, Finlayson, et al., 2023; Dakin, Stubbs, & Finlayson, 2023). We are currently extending this approach to develop and evaluate measures that capture different dimensions of motivation to eat **states**. Overall, we believe that such approaches will contribute to a more nuanced understanding of the motivations underlying eating behaviour traits and states, emphasising the utility of an eating behaviour motivation framework for identifying at-risk individuals and tailoring eating behaviour interventions to meet specific individual needs. We therefore suggest development and evaluation of this and/or similar models (e.g. Stevenson et al., 2023) may be a means of expanding, refining and psychometrically validating, theoretically informed, evidence-based measurements for the different dimensions of motivation to eat traits and states in the future.

3.2. *Strengths and limitations of the current study*

Strengths of the current study include an adequate sample size using multiple studies in a range of participants. Models were confirmed using data from the multi-centre DiOGenes trial, widening the sample demographic and increasingly the generalisability of findings, bearing in mind the limited sample size of 151 participants and the inability to conduct a measurement in variance analysis on this sample.

The study included data from paper and pen and electronic data collection methods. However, the study was limited by the fact that data for study 1 were collected primarily from the same laboratory. The study could be followed by an analysis including data from several laboratories around the world. Furthermore, in the current analysis data were largely limited to meal feeding situations and excluded interventions such as medications or procedures to treat obesity (Kadouh et al., 2019; Lynch et al., 2022; Saxena et al., 2021) that could possibly dissociate items from each other in the factor analysis. However, the current psychometric analysis suggests it is more likely that respondents to these questions view the questions as semantically similar. This does not mean people have important differences in dimensions of motivation to eat (e.g., Dakin, Beaulieu, et al., 2023; Dakin, Finlayson, et al., 2023; Dakin, Stubbs, & Finlayson, 2023; Stevenson et al., 2023). The four items covary sufficiently to support a one-factor solution, which may indicate they are interpreted similarly, though this cannot be confirmed directly because a 4-item scale cannot yield more than 1 factor. The sample of questions could be expanded to include the older 6-item scale and the sample of participants could be expanded to include a wider range of socioeconomic and demographic representation, which are aims of future studies. The associations between individual items, the compound item (motivation to eat) and external outcomes could also be expanded.

4. Conclusion and recommendations

The current studies used exploratory factor analysis and confirmatory factor analysis to assess the dimensional structure of the commonly used 4-item VAS method for tracking hunger, fullness, desire to eat and prospective consumption. Study 1 and 2 found strong evidence that these items are articulated as one underlying latent construct motivation to eat. We recommend using a composite score of the 4 VAS items for the assessment of overall motivation to eat states. While there were hints in our analysis of 27 years ago and in the current data set of slight variation between items in different states (e.g., fullness between fasted and fed states) or of a second mini-factor, the current analyses provide preliminary evidence that the 4-item scale does not differentiate psychometrically between theoretical constructs of hunger and satiety. It should therefore be used to assess the single latent construct of motivation to eat. Our previous analyses of motivation to eat traits (Dakin et al., 2024c; Dakin, Stubbs, & Finlayson, 2023; Stubbs et al., 2023) and Stevenson's analysis of interceptive hunger (Stevenson et al., 2023) suggest these constructs are multidimensional. We therefore recommend that future studies should develop, articulate, psychometrically validate and assess predictive capacity (e.g. in relation to eating behaviour) of theoretically-informed, evidence-based measurements that capture the different dimensions of motivation-to-eat/not-to-eat states. These could also be evaluated in relation to multidimensional motivation to eat traits (Dakin et al., 2024c; Dakin, Stubbs, & Finlayson, 2023; Stubbs et al., 2023) and states, such as interoceptive hunger (Stevenson et al., 2023).

CRediT authorship contribution statement

Clarissa A. Dakin: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cristiana Duarte:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kristine Beaulieu:** Writing – review & editing, Resources, Methodology, Data curation. **Nicola Buckland:** Writing – review & editing, Resources. **Michelle Dalton:** Writing – review & editing, Resources. **Anna Myers:** Writing – review & editing, Resources. **Catherine Gibbons:** Writing – review & editing, Resources, Methodology, Data curation. **Mark Hopkins:** Writing – review & editing, Resources, Methodology, Investigation, Conceptualization. **Graham Finlayson:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Molly Blakemore:** Writing – review & editing, Resources, Data curation. **R. James Stubbs:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization.

Research data

The current study combined data from multiple sources. The lead authors can share the dataset upon request.

Ethical statement

The current study combines data from available datasets of published studies which were performed in compliance with relevant laws and institutional guidelines and have been approved by the respective appropriate institutional committees.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2026.108457.

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